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Indian Standard

OIL AND GAS FIRED THERMIC FLUID HEATERS — METHOD OF CALCULATION OF FILM TEMPERATURE

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Chemical Engineering Plants and Related Equipment Sectional Committee, HMD 17

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Chemical Engineering Plants and Related Equipment Sectional Committee had been approved by the Heavy Mechanical Engineering Division Council.

With the advent of the need for higher and higher temperatures of operation in various process plants, thermic fluid heaters have become the choice to provide the process heat in preference to steam boilers due to the feasibility of attaining higher temperatures of the heating media without the necessity of maintaining high pressure. However thermic fluid has a tendency to degrade if subjected to higher than recommended temperatures and most of the thermic fluids are highly inflammable necessitating careful scientific approach to the design of equipment. While designing the combustion chamber of thermic fluid heaters, therefore, it is of primary importance that the thermic fluid film absorbing heat is not subjected to temperatures beyond its point of breakdown or its boiling point. The heat flow from the flame as well as the flue gases within the combustion chamber and the velocity of flow of the thermic fluid absorbing this heat need to be so adjusted that the film temperature is always below the critical limit.

The combustion chamber of a gas fired or oil fired thermic fluid heater is usually designed as a cylindrical chamber using helically wound tubes within which the burner fires from one end and the flue gases exit at the other end. Thermic fluid is pumped through the tubes to provide forced circulation. Shell type designs are not adopted because of the low velocities obtaining on the thermic fluid side and the consequent large possibility of too high a film temperature or of local boiling. Reversing flame designs of the combustion chamber are also not generally adopted due to the high heat flow necessitating very high velocities of thermic fluid with consequent large pressure drops.

Design and construction of thermic fluid heaters form very specialized fields of work with a lot of scope for continuous research and modifications. It is, therefore, attempted in this standard to cover only the basic requirements to ensure safety of the equipment, taking into consideration the prevalent industrial practice supported by the present level of theoretical information available. The designer should use research data as and when these become available.

In the formulation of this standard, considerable assistance has been derived from the following publications:

DIN 4754 : 1980 Warmeübertra gungsanlagen mit organischen flüssigkeiten, issued by Deutsches Institut für Normung (Germany).

API 530 : 1978 Recommended practice for calculation of heater tube thickness in petroleum refineries issued by American Petroleum Institute.

Indian Standard
OIL AND GAS FIRED THERMIC FLUID HEATERS — METHOD OF CALCULATION OF FILM TEMPERATURE

1 SCOPE

1.1 This standard specifies the method of calculation of maximum film temperature of thermic fluid occurring in heaters fired with either oil or gas as fuel with or without preheating of combustion air using single phase liquid flowing inside tubes. The method is valid for petroleum based thermic fluids as well as synthetic thermic fluids. This standard is not valid if two phase flows occur within the combustion chamber.

1.2 The standard is applicable for coil type combustion chambers as well as refractory lined combustion chambers with convection tube banks arranged within and or at the exit of the combustion chamber.

2 SYMBOLS, TERMINOLOGY AND FORMULAE

NOTE — In this standard the terms 'furnace' and 'combustion chamber' are used synonymously.

A_s = Surface area of the combustion chamber, m^2

B = Beam length due to the combustion chamber volume, m (*see* Table 1)

$$B = 3.6 V_F / A_s \qquad \text{...... (1)}$$

Typical values are given in Table 1

Table 1 Typical Values of Beam Length – 'B'

(*Clause* 2)

Sl No. (1)	Combustion Chamber Dimensional (2)	Beam Length (3)
1	Cube of edge '*a*'	0.60 *a*
2	Cylinder of diameter '*d*' and infinite length	0.90 *d*
3	Cylinder of height = diameter = '*d*'	0.60 *d*
4	Sphere of diameter '*d*'	0.60 *d*

C_v = nett calorific value of fuel, kJ/kg

C_{ap} = mean specific heat of air integrated to air preheat temperature, kJ/kg^{0}C

C_{fe} = mean specific heat of thermic fluid integrated to bulk temperature of furnace exit

C_{ff} = mean specific heat of thermic fluid integrated to the bulk temperature proximate to flame, kJ/kg

C_{ge} = mean specific heat of flue gases at constant pressure integrated to furnace exit temperature, kJ/kg^{0}C

C_{gf} = mean specific heat of flue gases at constant pressure integrated to flame temperature, kJ/kg^{0}C

C_{we} = mean specific heat of thermic fluid integrated to film temperature at furnace exit

C_{wf} = mean specific heat of thermic fluid integrated to the film temperature proximate to flame kJ/kg^{0}C

D_c = diameter of the combustion chamber (tube centre to tube centre) in the case of helical coils the diameter of the inscribed circle, (centre to centre of tubes) in the case of shapes other than cylindrical chambers (*see* Fig. 1)

d_{ff} = flame diameter, m

To be obtained from the burner manufacturer

d_{ie} = inner diameter of thermic fluid tube, at furnace exit, m

d_{if} = Inner diameter of thermic fluid tube proximate to flame, m

d_{oe} = outer diameter of thermic fluid tubes at furnace exit, m

d_{of} = outer diameter of thermic fluid tubes proximate to flame, m

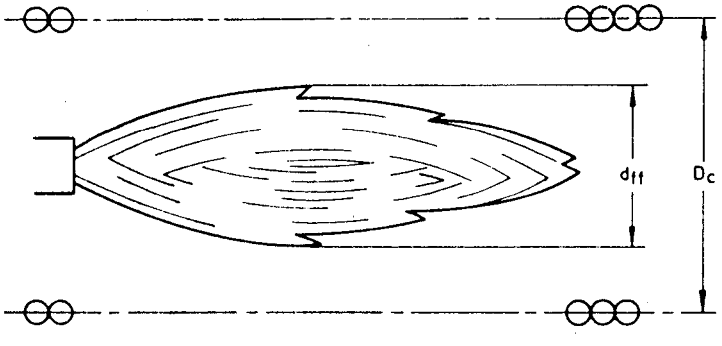

FIG. 1 COMBUSTION CHAMBER AND FLAME DIAMETER

e_f = flame emissivity

$e_f = Y.d_{ff}^{z}$ …… (2)

NOTES

1 Values of Y and Z are to be obtained from the appropriate table for the type of fuel (*see* 3 for tables)

2 Values of 'e_f' may be interpolated linearly between neighbouring calculated values of e_f for intermediate values of $(D_c - d_g)$. *See* Annex A, for example.

F_c = radiation heat flux due to carbon dioxide, W/m^2

F_E = heat flux at the furnace exit, W/m^2

F_F = heat flux due to flame proximity, W/m^2

F_H = radiation heat flux due to water vapour, W/m^2

F_o = convection heat flux due to flue gas in cross flow at the exit, W/m^2

f_c = factor to account for increase in heat transfer due to secondary flows.

= $1 + 3.54 . (d_{if}/D_c)$ for helical coils proximate to flame …… (3)

= $1 + 3.54 . (d_{ie}/D_c)$ for helical coils at furnace exit …… (4)

= 1 in other cases

f_e = factor for rough approximation of furnace exit temperature

f_e = 0.85 for refractory furnaces, and

f_e = 0.66 for coil type combustion chambers

f_{fe} = factor for variable physical properties of thermic fluid at furnace exit

$f_{fe} = (P_{fe}/P_{we})^{0.11}$ …… (5)

f_{ff} = factor to account for variable physical properties of thermic fluid proximate to flame

$f_{ff} = (P_{ff}/P_{wf})^{0.11}$ …… (6)

f_{pc} = factor for calculating peak convection flux in cross flow from the circumferential average convection flux

= 1.6 for configurations of furnace exit with unrestricted entry of flue gases into in-line tube banks

= 1.9 when tubes are placed across the flue gas path except within in-line tube banks

f_{vg} = factor to account for variable physical properties of flue gas

$f_{vg} = (T_{ge}/T_{we})^{0.12}$ …… (7)

G_{fe} = mass velocity of thermic fluid through the inside cross section of tube at furnace exit, kg/s m^2

G_{ff} = mass velocity of thermic fluid through the inside cross section of the tube proximate to flame, kg/s m^2

G_{ge} = mass velocity of flue gas through the gap between tubes at furnace exit, kg/s m^2

g_t = gap between tubes across flue gas flow at furnace exit, m

H = heat input per kg of fuel, kJ

$H = C_v + m_a . C_{ap} . (t_{ap} — t_a)$ …… (8)

h_{ie} = inside heat transfer coefficient for thermic fluid tubes at furnace exit, W/m^{2}K

h_{if} = inside heat transfer coefficient for thermic fluid tubes due to proximate to flame, W/m^{2}K

h_o = convection heat transfer coefficient in cross flow at furnace exit, W/m^{2}K

k_{fe} = conductivity of thermic fluid at the bulk temperature at furnace exit, W/mK

K_{ff} = conductivity of thermic fluid at the bulk temperature proximate to flame, W/mK

K_{ge} = conductivity of flue gas at the furnace exit temperature, W/mK

K_{me} = conductivity of the tube material at furnace exit, W/mK

K_{mf} = conductivity of tube material proximate to flame, W/mK

K_{we} = conductivity of thermic fluid at film temperature at furnace exit, W/mK

K_{wf} = conductivity of thermic fluid at the film temperature proximate to flame, W/mK

m_a = mass of air used per kg of fuel, kg
To be measured or

$m_a = m_s (1 + X_a/100)$ …… (9)

m_g = mass of flue gas produced per kg of fuel, kg

$m_g = m_a + 1$ …….(10)

m_s = mass of air for stoichiometric combustion per kg of fuel, kg

N_m = mean Nusselt number of flue gas at furnace exit

P_c = percentage carbon dioxide in flue gas

P_{fe} = prandtl number of thermic fluid at the bulk temperature of fluid at furnace exit

$P_{fe} = C_{fe} . \nu_{fe}/K_{fe}$ …….. (11)

P_{ff} = prandtl number of thermic fluid at the bulk temperature of thermic fluid proximate to flame

$P_{ff} = C_{ff} . \nu_{ff}/K_{ff}$ …….. (12)

P_{ge} = prandtl number of flue gas at furnace exit

$P_{ge} = C_{ge} . \nu_{ge}/K_{ge}$ …….. (13)

P_H = percentage water vapour in flue gas

P_{we} = prandtl number of the thermic fluid at the wall temperature at furnace exit

$P_{we} = C_{we} . \nu_{we}$ …….. (14)

P_{wf} = prandtl number of thermic fluid at the inside wall temperature of the tube proximate to flame

$P_{wf} = C_{wf} . \nu_{wf}/K_{wf}$ …….. (15)

R_{ec} = reynolds number of flue gas at furnace exit

R_{fe} = reynolds number of thermic fluid at the bulk temperature at furnace exit

$R_{fe} = d_{ie} . G_{fe}/v_{fe}$ .... (16)

R_{ff} = reynolds number of the thermic fluid at the bulk temperature proximate to flame

$R_{ff} = d_{if} . G_{ff}/v_{ff}$ .... (17)

S = factor based on Stephan Boltzman constant = 5.67

T_f = flame temperature, K to be measured or

$T_f = (T_{ge} . T_{fA})^{0.5}$ .... (18)

T_{fA} = adiabatic flame temperature, K

$T_{fA} = t_{fA} + 273$ .... (19)

T_{ge} = temperature of flue gas at furnace exit, K

$T_{ge} = t_{ge} + 273$ .... (20)

T_{we} = tube outside temperature at furnace exit, K

$T_{we} = t_{we} + 273$ .... (21)

T_{wf} = wall temperature outside tubes proximate to flame, K

$T_{wf} = t_{wf} + 273$ .... (22)

t_a = ambient temperature, °C

t_{ap} = air preheat temperature, °C

t_{be} = thermic fluid bulk temperature at furnace exit, °C (*see* Fig. 2)

t_{bf} = thermic fluid bulk temperature proximate to flame, °C

NOTE — To be taken at a point on the tube approximately 1/3rd the flame length from the burner nozzle tip along the axis of the flame in the case of oil flames and approximately 2/3 rd the flame length from the nozzle tip in the case of gas flames.

t_{fA} = adiabatic flame temperature, °C

$H/(C_{gf} . m_g) + t_a$ .... (23)

t_{fe} = film temperature at furnace exit, °C (*see* Fig. 2)

t_{ff} = film temperature due to proximity of flame, °C (*see* Fig. 2)

t_{ge} = temperature fo flue gas at furnace exit, °C

t_{te} = thickness of the tube wall at furnace exit, *m*

t_{tf} = thickness of the tube wall proximate to flame, *m*

t_{we} = tube outside temperature at furnace exit, °C

t_{wf} = temperature outside the tube wall proximate to flame, °C

V_F = volume of the combustion chamber, m³

V_{fe} = dynamic viscosity of thermic fluid at bulk temperature at furnace exit, N. s/m²

v_{ff} = dynamic viscosity of thermic fluid at the bulk temperature proximate to flame, N. s/m²

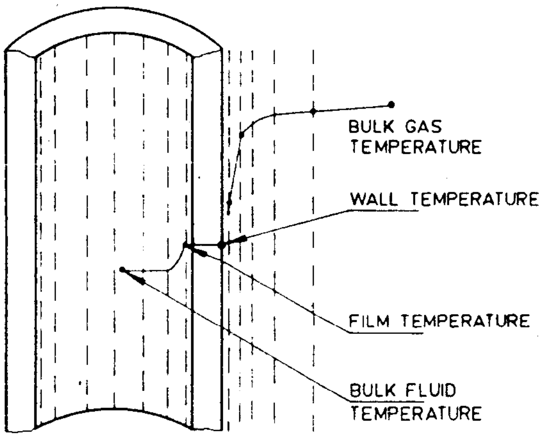

FIG. 2 TEMPERATURE GRADIENT ACROSS THE TUBE

v_{ge} = dynamic viscosity of flue gas at the furnace exit temperature, N. s/m²

v_{we} = dynamic viscosity of thermic fluid at the film temperature at the furnace exit, N. s/m²

v_{wf} = dynamic viscosity of thermic fluid at the film temperature proximate to flame, N. s/m²

X_a = excess air percentage of combustion air

3 TABLES FOR CALCULATION OF 'ef' FOR VARIOUS FUELS (TABLES 2 TO 4)

Table 2 Gaseous Hydrocarbons

(*Clauses* 2 *and* 3)

	$d_{ff} \leq 1.0$		$d_{ff} > 1.0$	
$D_c - d_{ff}$	Y	Z	Y	Z
3.0	0.175	0.910	0.183	0.569
2.0	0.182	0.875	0.192	0.578
1.0	0.205	0.969	0.212	0.591
0.6	0.214	0.963	0.228	0.606
0.2	0.246	0.823	0.251	0.614
0.0	0.269	0.820	0.273	0.587

Table 3 Petroleum Oils of 50°C Kinematic Viscosity Less Than 250cS

(*Clauses* 2 *and* 3)

	$d_{ff} \leq 1.0$		$d_{ff} > 1.0$	
$D_c - d_{ff}$	Y	Z	Y	Z
3.0	0.414	0.682	0.419	0.245
2.0	0.432	0.667	0.439	0.228
1.0	0.481	0.649	0.487	0.246
0.6	0.495	0.634	0.516	0.254
0.4	0.522	0.643	0.550	0.239
0.2	0.542	0.653	0.583	0.227
0.1	0.554	0.622	0.601	0.233
0.0	0.582	0.628	0.629	0.241

Table 4 Petroleum Oils of 50°C Kinematic Viscosity of 250cS or Above

(*Clauses* 2, 3 and *Annex* A)

$D_c - d_{fl}$	$d_{fl} \leq 1.0$		$d_{fl} > 1.0$	
	Y	Z	Y	Z
3.0	0.419	0.629	0.442	0.197
2.0	0.436	0.582	0.458	0.202
1.0	0.484	0.578	0.508	0.215
0.6	0.534	0.601	0.554	0.204
0.4	0.575	0.631	0.591	0.194
0.2	0.607	0.638	0.627	0.177
0.1	0.625	0.631	0.641	0.189
0.0	0.649	0.617	0.667	0.190

4 THEORETICAL BACKGROUND

4.1 When heat is absorbed by thermic fluid in the fired heaters, it is essential to limit the highest temperature attained by the thermic fluid film adjacent to the inside metal wall of the tube through which it flows to prevent undue deterioration of the fluid and the consequent dangers. It is also imperative that there is no localized boiling within the film in order to control fatique of the tube walls. These requirements in turn make it mandatory that thermic fluid heaters are made such that there is reasonable guarantee that the film temperature allowed by the manufacturer of the thermic fluid is not exceeded.

4.2 The film temperature of the thermic fluid can be calculated if the heat flux through the film is known. The difference between film temperature and the bulk temperature of the fluid would be the product of film resistance and the heat flux. Thus,

$$t_f = F_p \cdot (1/h_i) + t_b \quad \text{..........} (24)$$

where

t_f = film temperature of the thermic fluid, °C;

F_p = heat flux at the point under consideration, W/m^2;

h_i = inside heat transfer coefficient for thermic fluid tubes, W/m^{2}K; and

t_b = thermic fluid bulk temperature, °C.

The method of calculation of the film temperature thus boils down to calculating the inside heat transfer coefficient of the thermic fluid and the corresponding heat fluxes at point where high heat fluxes are expected.

4.3 The maximum heat flux may occur at the point where the visible flame is the closet to the tubes. At this point one can expect the highest radiation from the flame with some additional convection. It is also possible that the maximum heat flux occurs where the flue gases exit from the combustion chamber and enters the convection bank where there may be quite high radiation coupled with high convection. The film temperatures need to be calculated at these points and the higher temperature need to be limited to the acceptable value. While calculating the heat flow, the gas side heat transfer coefficient controls the flux since the metal conductivity of the tubes as well as the inside heat transfer coefficient is very large when compared to the gas side coefficient.

4.4 In a coil type heater, the radiation heat flux at the point where the flame is closest to the coil is a function of the ratio of flame diameter to the combustion chamber diameter. The *Stefan Boltzman* equation for radiation can be modified to include effective flame emissivity and the diameter ratio to give the radiant heat flux at this point.

4.4.1 A fixed addition of 15 percent to account for additional convection is an accepted practice in industry for normal flames for the calculation of film temperature. For reversing flames the convection coefficient is very much higher and at present need to be back calculated from measured values of flue gas temperature at the exit from the combustion chamber since no method of prediction is yet available in published literature.

4.4.2 Prediction of the luminous flame temperature is traditionally carried out by calculating the geometric mean of the adiabatic combustion temperature and the furnace exit temperature.

4.4.2.1 The adiabatic combustion temperature is calculated by first determining the mean specific heat of the combustion products at constant pressure integrated from the air preheat temperature to the flame temperature and then evaluating the adiabatic temperature from the knowledge of the mass of the combustion products and heat input. The specific heat is to be calculated using the specific heats of the constituents proportionally. The heat input is the sum of the nett calorific value of the fuel and the heat in the preheated air per kg of fuel.

4.4.2.2 The furnace exit temperature should be evaluated using relevant well known methods or by direct measurement. When elaborate calculations are not contemplated a conservative estimate of flue gas exit temperature can be made assuming that 66 percent of the heat released in the coil type combustion chamber is carried away by the flue gas at the exit. In the case of refractory furnace such a conservation estimate can be made assuming that 85 percent of the heat released in the flue gas is carried to the inlet of the convection bank, provided if at least one side of the combustion chamber is fully exposed to the convection bank. Such rough estimates however are not recommended as the design then tends to be crude though conservative and safe. A more precise evaluation of the flue gas exit temperature is strongly recommended.

4.5 The heat flux at the exit of the combustion chamber may be calculated by adding the convection heat flux to the radiant heat flux.

4.5.1 Gas radiation may be calculated from the knowledge of the flue gas exit temperature using a thermocouple or may be calculated using an appropriate procedure as mentioned at **4.4.2.2**.

4.5.1.1 The radiant heat flux is calculated as a function of the beam length of the furnace, percentages of carbon dioxide and water vapour in the flue gas and the exit temperature.

4.5.2 The convection heat flux from the flue gas may be evaluated by calculating the gas side heat transfer coefficient. Correlations between Nusselt number, Reynolds number and Prandtl number are available depending on the configuration of tubes at the exit. Almost in all cases tubes are placed across the flue gas flow and hence it will be seen that invariably correlations for cross flow are relevant.

4.5.2.1 It will be seen that the maximum heat flux occurs on the front face of the tubes across the flow. The variation between the peak heat transfer and the average heat transfer around the tubes in cross flow has a ratio of approximately 1.6 to 1.9 depending on the geometry of the channel. A value of 1.6 will be used for flue gases having unrestricted entry directly into in-line tube banks at the end of the combustion chamber and 1.9 for all other cases.

4.5.2.2 The method of calculation adopted for the convection heat flux into the tubes at the combustion chamber exit or into the tubes facing the chamber is valid for single tubes as well as for the first row of a tube bank. The direction of heat flow is accounted for.

4.6 The inside heat transfer coefficient is calculated using the simplified Gnielinski correlation which is valid for the range of Reynolds numbers and Prandtl numbers relevant for thermic fluid heaters.

4.6.1 Correction factor for the enhancement of heat transfer due to the increased turbulance at the tube entry is not required as this is not relevant while calculating the heat transfer coefficient at a point quite away form the thermic fluid entry into the tubes.

4.6.2 There is an increase in the heat transfer coefficient due to secondary flow patterns in coils and hence a correction factor is included.

4.7 The bulk temperature at the relevant point is to be assessed depending on the location of the point in consideration. Linear interpolation of the bulk temperature between the inlet and outlet of the combustion chamber may be done as required.

4.7.1 The point of the highest flux due to proximity of flames may be taken at a distance one third the length of flame in front of the burner tip in the case of oil flames and two thirds the length of the flame in front of the burner tip in the case of gas flames.

5 CALCULATION OF FILM TEMPERATURE DUE TO PROXIMITY OF FLAME

5.1 This evaluation is to be carried out in the case of combustion chambers with heat absorbing tubes along the wall. If flue gas exit from a furnace comprising refractory walls with no tube on the walls the calculation given in **6** need only be carried out.

5.2 A reasonable value of the wall temperature, t_{wf} is assumed and the flux and film temperature are calculated. Once the film temperature is calculated, the wall temperature needs to be checked back and seen that it is within 5°C of the assumed value.

5.3 Peak heat flux due to proximity of flame

$$F_F = 1.15 \,.\, (d_{ff}/D_c) \,.\, e_f \,.\, S \,.\, \left[\left(\frac{T_f}{100}\right)^4 - \left(\frac{T_{wf}}{100}\right)^4\right] \quad \text{........ (25)}$$

5.4 Inside heat transfer coefficient

$$h_{if} = 0.012 f_c . f_{ff} (K_{ff}/d_{if}) \,.\, (R_{ff}^{0.87} - 280) \,.\, P_{ff}^{0.4} \quad \text{........ (26)}$$

This equation is not valid for R_{ff} less than 2 300; but such a situation does not arise in fired thermic fluid heaters, the velocity then being too low.

5.5 Film temperature

$$t_{ff} = F_F/h_{if} + t_{bf} \quad \text{........ (27)}$$

5.6 Wall temperature

$$t_{wf} = t_{ff} + F_F \,.\, t_{tf}/K_{mf} \quad \text{........ (28)}$$

6 CALCULATION OF FILM TEMPERATURE AT THE EXIT OF THE FURNACE

6.1 A reasonable value of the wall temperature, t_{we} is assumed and the flux calculated. Once the film temperature is calculated, the wall temperature needs to be back calculated and seen that it is within 5K of the assumed value.

6.2 Heat Flux Due to Radiation at the Exit of Furnace

6.2.1 *Heat Flux Due to Carbon Dioxide*

$$F_c = 0.89\,(P_c \,.\, B)^{0.33} \left[\left(\frac{T_{ge}}{100}\right)^{3.5} - \left(\frac{T_{we}}{100}\right)^{3.5}\right] \quad \text{........ (29)}$$

6.2.2 *Heat Flux Due to Water Vapour*

$$F_H = 1.022\, P_H^{0.8} \,.\, B^{0.6} \left[\left(\frac{T_{ge}}{100}\right)^{3} - \left(\frac{T_{we}}{100}\right)^{3}\right] \quad \text{........ (30)}$$

6.3 Heat Flux Due to Convection at Exit of Furnace

If the flue gases exit from the furnace without any tubes across the flue gas path, the following convection calculation need not be done and F_0 may be taken as 0.

6.3.1 Reynolds number for calculating heat transfer coefficient across tubes

$$R_{ec} = 1.57\, G_{ge} \,.\, M_1 \,.\, d_{oe}/(M_2 \,.\, V_{ge}) \quad \text{...... (31)}$$

where

$$M_1 = g_t/(g_t + d_{oe}) \qquad \text{........ (32)}$$

$$M_2 = 1 - 0.785 \,.\, M_3 \qquad \text{........ (33)}$$

$$M_3 = d_{oe}/(g_t + d_{oe}) \qquad \text{........ (34)}$$

6.3.2 Nusselt number for cross flow

$$N_M = 0.3 + (N_L{}^2 + N_T{}^2)^{0.5} \qquad \text{........ (35)}$$

where

$$N_L = 0.664 \,.\, R_{ec}{}^{0.5} \,.\, P_{ge}{}^{0.33} \qquad \text{........ (36)}$$

$$N_T = \frac{0.037\, R_{ec}{}^{0.8} \,.\, P_{ge}}{1 + 2.443\, R_{ec}{}^{-0.1} \,.\, (P_{ge}{}^{0.66} - 1)} \qquad \text{........ (37)}$$

6.3.3 Outside convection heat transfer coefficient in cross flow

$$h_o = 0.637\, N_M \,.\, K_{ge}/d_{oe} \qquad \text{........ (38)}$$

6.3.4 Peak convection heat flux

$$F_o = h_o \,.\, (t_{ge} — t_{we}) \,.\, f_{vg} \,.\, f_{pc} \qquad \text{........ (39)}$$

6.4 Peak heat flux at the furnace exit

$$F_E = F_c + F_H + F_o \qquad \text{........ (40)}$$

If F_o is taken as 0 as allowed in **6.3**; the value of F_E is to be increased by a factor of 1.15 to take into account convection at exit.

6.5 Inside heat transfer coefficient at the point above

$$h_{ie} = 0.012\, f_c \,.\, f_{fe} \,.\, (k_{fe}/d_{ie}) \,.\, (R_{fe}{}^{0.87} - 280) \,.\, P_{fe}{}^{0.4} \qquad \text{...... (41)}$$

This equation is not valid for R_{ef} less than 2 300 but such a situation does not arise in fired thermic fluid heaters. The velocity then being too low.

6.6 Film temperature at furnace exit (*see* Fig. 2)

$$t_{fe} = F_E/h_{ie} + t_{be} \qquad \text{........ (42)}$$

6.7 Tube outside temperature at furnace exit

$$t_{we} = t_{fe} + F_E \,.\, t_{te}/K_{me} \qquad \text{........ (43)}$$

7 FILM TEMPERATURES

7.1 The maximum film temperature in the heater is the higher of t_{ff} and t_{fe}.

7.2 If the maximum film temperature is higher than the recommended value, the design of the thermic fluid heater needs to be changed or the firing rate reduced such that the maximum film temperature is maintained within the acceptable limit.

ANNEX A

(*Clause* 2)

EXAMPLE FOR CALCULATION OF e_f

Let us consider a case where heavy oil is being used and we have:

d_{ff} = 0.9 m

and D_c = 1.45 m

Then $D_c - d_{ff}$ = 1.45 − 0.9

= 0.55 m

To calculate 'e_f' for $D_c - d_{ff}$ = 0.55, we proceed as below:

When $D_c - d_{ff}$ = 0.6, then using Table 4 and equation (2) we have:

$$e_f = 0.534 \times 0.9^{0.601}$$
$$= 0.501$$

when $D_c - d_{ff}$ = 0.4, then using Table 4 and equation (2) we have:

$$e_f = 0.575 \times 0.9^{0.631}$$
$$= 0.538$$

By linear interpolation for 'e_f' when $D_c - d_{ff}$ = 0.55; we have:

$$e_f = 0.538 + \frac{(0{\cdot}501 - 0.538)}{(0.6 - 0.4)} \times (0.55 - 0.4)$$

$$= 0.510$$

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